disP - The Planning Review

Interdisciplinarity in transdisciplinary projects: circulating knowledges, practices and effects

--Manuscript Draft--

Full Title:	Interdisciplinarity in transdisciplinary projects: circulating knowledges, practices and effects
Manuscript Number:	RDSP-2016-0038R1
Article Type:	Manuscript
Keywords:	Interdisciplinarity; Transdisciplinarity; practices
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Abstract

This article argues that the emphasis on solving substantive "real world" problems through interdisciplinary research collaboration can neglect the wider value created by such collaborations. Championing the role of a knowledge integration and reflection facilitator, the article contends that more recognition be given to the value of 'spillover' effects associated with interdisciplinary modes of working, rather than focusing solely on knowledge outputs and impacts. Drawing on embedded research conducted in relation to a project on local energy futures involving physicists, architects and geographers, the paper illustrates such 'spillover' in relation to academic practice in teaching, project management; and research methods. Such spillovers signal that what travels in interdisciplinary working is much more than formal knowledge and point to potential long term legacy effects from interdisciplinary working, back in disciplines.

1. Introduction

Collaborative working between different disciplines has become a highly desirable feature of academic research, prized by both funders and research assessors. Interdisciplinarity, multidisciplinarity and transdisciplinarity, occupy a central position within contemporary research frameworks, not least because of an ongoing conception within academia that such collaborations have the ability to provide substantive solutions to 'real world' problems. These issues are regularly described as not fitting neatly into disciplinary shaped boxes (Jeffrey, 2003), whilst the 'promised land' (Jasanoff, 2013:99) of collaboration is seen to offer hope in solving some of the 'wicked problems' of the Anthropocene (Sardar, 2010) – climate change, food poverty, sustainability. Drawing upon Science and Technology Studies (STS) literature, such collaborations are seen to exemplify Mode 2 knowledge formation; an approach defined by Gibbons et al. (1994) to distinguish the paradigm of scientific discovery, characterised by homogeneity, hierarchy and scientific autonomy, from that of a newer, softer paradigm of knowledge production. Here, a focus on complexity, non-linearity and heterogeneity (Thompson Klein, 2014) inverts the 'traditional domain of 'hard facts' over 'soft values' (Funtowitz & Ravetz, 1993:750) and non-academic actors (Pohl, 2011) and stakeholders can become engaged in projects 'upstream', at the start of research (Delgado et al., 2011; Nowotny et al., 2001).

Yet ambiguity reigns over exactly what interdisciplinarity and its many guises are and, furthermore, how one goes about determining if it has taken place and the value it has added. Useful classifications are provided by various esteemed scholars within the field (see Barry et al., 2008; Huutoniemi et al., 2010; Jasanoff, 2013; Whatmore, 2013). However, confusion persists with regards to identifying interdisciplinarity and its counterparts - multi and trans - and significantly what counts as 'successful' interdisciplinary collaboration. To that end, appraising interdisciplinarity is fraught with difficulties. Many studies note the problems of evaluation citing: a lack of assessment methods (Fazey et al., 2014); effective criteria (Pilnick, 2013); and recognisable hallmarks of quality (Carew and Wickson, 2010), as just a few of the reasons. Issues remain over how interdisciplinary research is valued, particularly given its often complex and heterogenous nature. With limited examples of large scale evaluations of interdisciplinary projects, calls are being made for recognition of research fields that study the process of interdisciplinary research itself (Fazey et al., 2014; Lyall et al., 2015). A recent drive encouraging reflexive approaches within interdisciplinary, and particularly transdisciplinary studies, is also growing in momentum (Popa et al., 2015). Scholars have noted the difficulty in accounting for the vast experiential value which is produced by such collaborations and which is often 'lost when members go their separate ways' (Jeffrey, 2003: 559; see also Lyall et al., 2015).

The article draws upon the experience of one team member who used embedded ethnographic techniques in our interdisciplinary project exploring energy futures with a public. We have termed this team member's role the 'knowledge integration and reflection facilitator', as it was their primary responsibility to encourage and enable team members to be reflexive about the research process and keep interdisciplinarity at the core of reflection. Furthermore, this role focused attention on interdisciplinarity as produced in the enactment of a particular project (see also Donaldson et al., 2010). Understanding and approaching interdisciplinarity in this way has foregrounded the importance of the experiential knowledge and 'spillover' effects such working creates. However, unlike other transdisciplinary/interdisciplinary studies, a key outcome of this project and the role of the knowledge integration and reflection facilitator is the emphasis placed on the mundane and everyday experiential effects of interdisciplinary working. In line with other studies, the article argues that the project and its effects are a transdisciplinary endeavour.

The article begins with a critique of the existing literature and approaches to recognising the value of interdisciplinary working. A brief introduction to the project follows, proceeded by a discussion around the embedded ethnographic method used to elicit reflection and evaluation of the research process and the subsequent enactment of interdisciplinarity. The main argument of the article details the circulating knowledges and practices which have 'spilled over' from one discipline into others as a result of being part of this project. 'Spillover' effects are argued to be part of a transdisciplinary endeavour. In keeping with the method of project-based ethnography, the paper has multiple voices. The main authorial voice of the article is that of the person conducting the embedded ethnographic research with the team- the knowledge integration and reflection facilitator; the 'I' who draws upon discussions and reflections had with, and, as part of, the project team. This voice is interspersed with a collective 'we' or 'our', to signal a subtle but important shift between the author writing about her role, as the knowledge integration and reflection facilitator, and that of the wider team's reflections on interdisciplinarity.

2. Creating and evaluating interdisciplinarity

The drive for interdisciplinary research is coming from all corners of academia. With funding bodies, including the AHRC, ESRC, EPSRC and NERC, all making interdisciplinarity a key research priority (Lyall et al. 2013; Wainwright et al., 2014), collaborating with other disciplines has never been more popular. Consequently, a plethora of studies have emerged detailing the ideal conditions for successful interdisciplinarity, as well as highlighting many of the barriers. Suggestions regarding the need for physical proximity to colleagues (Carew and Wickson, 2010; Stokols, 2006); the creation of a common language (Bracken and Oughton, 2006; Jeffrey, 2003), collective goals (Stokols, 2006) and good communication (Bruce et al., 2004); appreciating the values and approaches of other disciplines (Lau and Pasquini, 2008; Lele and Norgaard, 2005; Lyall and Meagher, 2012; Stokols, 2006); and having the right configuration of disciplines (Bruce et al., 2004; Depres and Lawrence, 2004) provide useful pointers for potential interdisciplinary collaborations. Aligned with this guidance for successful interdisciplinary collaboration is the drive from STS to ensure that such research is producing 'socially robust knowledge' (Nowotny, 1999). 'Upstream' working (Delgado et al., 2011), engaging with Mode 2 forms of knowledge production is increasingly the norm in interdisciplinary projects seeking to research socially robust orientations to the 'grand challenges' of contemporary times (OECD, 2010; Warnke and Schirrmeister, 2016); Mode 2 knowledge production being defined by its antithetical reflection of Mode 1 (Gibbons et al., 1994). The latter representing 'traditional elitist science', whereby uncertainties are managed and values unspoken (Funtowitz and Ravertz, 1993); and the former signifying 'post normal science' which is 'more reflexive, more responsible, more inclusive and more equal' (Jasanoff, 2013: 101).

Numerous critiques flourish amongst this brief synopsis of interdisciplinary and STS literature. For example, regarding the originality of the Mode 1/Mode 2 dichotomy (Etzkowitz and Leydesdorff, 2000); the politicisation of public engagement (Wynne, 2007 and Delgado et al., 2010); whether science has ever been normal (Goemine, 2011 and Healy, 2011); and if the quest for socially robust knowledge is actually a 'Trojan Horse' (Demeritt, 2000 and Popa et al., 2015). Indeed, as Popa et al., (2015:54) conclude 'scientific reliability, social relevance and social legitimacy', are 'traded off against one another' in the quest for appropriate knowledge production. Similarly, work emerging from the Zurich 2000 convention has highlighted many of these debates (see Thompson Klein et al., 2001). In this work the focus is on transdisciplinarity defined as a process which 'organises mutual learning among members of science and society that can generate socially robust knowledge' (Scholz, 2011: 375). Such work is focused on the outcome of socially robust orientations, through transdisciplinary processes which complement, rather than substitute, disciplinary and interdisciplinary activities (Scholz and Steiner, 2015). In doing so, such studies question whether Mode 2 approaches replace Mode 1, or if the two can exist in tandem, enabling a successful trade

off in Popa et al.'s, (2015) terms. These debates connect with ongoing discussions regarding 'successful' interdisciplinarity and transdisciplinarity.

As Mitchell et al., (2015) have argued there is an inherent focus within interdisciplinarity and transdisciplinarity, much aligned with the above trade off scenario, on having the right processes to yield the right outcomes- notably publications and public/stakeholder collaboration. The notion of what constitutes interdisciplinary success has been brought into question, with Fazey et al., (2014:217) concluding that 'success can be multidimensional, subjective and difficult to define' (see also Buanes and Jentoft, 2009). Donaldson et al. (2010) posit that interdisciplinary research needs to stop trying to 'iron out' its mess and instead embrace its complexity. In keeping with this attention to the plurality of interdisciplinary research, there has been a recent push from transdisciplinary studies for more emphasis on the role of reflexivity (Klay et al., 2015; Mierlo etal., 2010; Polk, 2015; Popa et al., 2015). Whilst reflexivity has always been a feature of transdisciplinarity, Popa et al., (2015: 54) describe a contemporary pragmatist approach to reflexivity involving a 'critical deliberative process based on evolving values and understandings'. Wenger's (1998) concept of communities of practice is utilised by some of this literature to make sense of how transdisciplinary collaborations (in most of these cases) engage in processes of collective learning and meaning making (Polk et al., 2015, Pohl 2010), being both 'iterative and adaptive' to their circumstances (Popa et al., 2015: 57). Mitchell et al., (2015: 92) use the term 'stocks' and 'flows' to describe how knowledge operates within transdisciplinary research, and how these 'occur via things that others can find, engage with, apply and/or adapt, and include tangible and accessible knowledge artefacts'. Similarly Scholz (2011) referring to the Zurich 2000 definition of transdisciplinarity, distinguishes between research and process. In this definition transdisciplinary processes are jointly controlled between academics, decision makers and stakeholders and provide the arena for mutual learning, whereas research is controlled by academics. Thus, the 'experiential' within transdisciplinary and interdisciplinary collaborations is also gaining traction. Building on Michael Polanyi's (1958) seminal writing on tacit knowledge, the experiential within STS has been discussed by Collins and Evans (2002, see also Collins, 2001), arguing for a Third Wave of Science Studies focusing on expertise and experience. Gorman (2002) builds upon this idea by uniting a focus on expertise with Galison's (1997) concept of 'Trading Zones' and how knowledge may be shared between disciplines. For Mitchell et al., (2015: 92) 'collaborators should come away with new perspectives, new orientations, new strategies, and new tools – seeing and doing things differently as a result of their experience of transdisciplinary research'. In conjunction with this are efforts to find methods to recognise and capture this somewhat slippery experiential component (Lyall et al., 2015, Popa et al., 2015). It is here where this paper sits; uniting a focus on the multiple and potentially fragmented experiential possibilities of interdisciplinary/transdisciplinary research with an approach to enhance, recognise and capture the often overlooked 'spillover' effects collaborative working can generate.

3. The project

Solar Energy for Future Societies (SEFS) was a four year EPSRC funded project, beginning in 2011, with the objective of experimenting with participatory methods in science and technology research. The team consisted of seven colleagues from Physics, Architecture and Human Geography all working together with a public in Stocksbridge, Sheffield, to investigate future scenarios of local sustainable energy provision (see: *Supplementary Information - Figure 1* for further details about the team members). Some members of the team had previously worked together, albeit not as closely or with such a sustained focus. For example, the Principal Investigator, from Physics, had connections with one of the human geography members through a previous and much larger physical sciences-led project. Likewise, the Architecture member had connections with one of the Geographers having met them at a university event. Thus, previous research networks were built upon. The project was informed by the substantive motivation for involving 'lay publics' in science

and technology debates as uncertified experts (Lane et al., 2011), to produce mutual learning between academics and public stakeholders; a space of 'science for' but also 'science with society' (Scholz, 2011: 401). The aim was to co-produce knowledge about the issues of future local energy provision in the urban environment rather than be driven to providing solutions to problems.

Participants were recruited through an exhibition on the potential futures of the energy system in Stocksbridge, organised by the SEFS team. 12 workshops followed, occurring every four to eight weeks (see: *Supplementary Information - Figure 3*), alongside more informal weekly drop-in sessions organised at a local café. The closing event was a second public exhibition, organised by the resident participants with the aid of the academic team. The aim of the workshops was to create an experimental space where future local energy scenarios and technologies could be explored using a variety of methods, with the project acting as the catalyst to bring together a diverse spectrum of local people and academics, each with their own interests and values. As a result, five sub-projects emerged focused on transforming the local urban environment. These were: sustainable ways of producing local food; improving local public transport; improving local community buildings; educating Stocksbridge residents about sustainability issues; and finding locally appropriate ways of generating, distributing and storing energy within the community. Example achievements from these five projects included designs to improve the energy efficiency of community buildings and substantial participant research into the potential of geothermal systems using the valley's disused mine network. As the project progressed, a core participant group emerged which has eventually become the Renewable Energy Upper Don Group (RUDEG). Following the completion of the SEFS project, RUDEG continues to develop and implement the ideas discussed during the SEFS workshops, ensuring that energy issues remain a focal point in transforming Stocksbridge.

Whilst this experimental participatory approach was the key strand of the research design, it was complemented by an inward focus on the experiential and capacity building effects of the academics involved; and it is to this that the remainder of the paper turns to. Before doing, it must be noted that this paper has deliberately not addressed the impact on non-academic partners, and the circulations of knowledge between academic and non-academic stakeholders. This is primarily because of the wide ranging transformative effects both within and between these stakeholders, which deserves a more thorough and separate analysis than this paper can devote. This will be dealt with in forthcoming project publications (see Authors, 2016). It may be argued that separating the two is impossible, with one inflected in the other, however, this paper has chosen to focus solely on the academic effects of interdisciplinary working.

4. Method: embedded ethnographic approach

In conjunction with the overall experimental approach of the research design of the project was an objective to encourage capacity building through the development of interdisciplinary approaches amongst the research team. Thus, the structural context of our project was one with the luxury of affording both time and funding to encourage and evaluate interdisciplinarity and to employ somebody specifically to do that. This was my role - to use my extensive knowledge and experience of ethnographic techniques, to explore, encourage and evaluate interdisciplinary, transdisciplinary and knowledge exchange practices within the research team, through a framework of reflexive appraisal. This role is best described as a knowledge integration and reflection facilitator. Such an approach is different from classic ethnographic approaches in that this was very much 'project' based and involved using ethnographic techniques, as opposed to conducting 'an ethnography'. The latter conducted most notably within STS in Latour and Woolgar's (1979) ground-breaking 'Laboratory Life' study (see Schlecker and Hirsch, 2001; and Strathern, 2004 on the use of ethnographic techniques within STS). Rather, my approach was part of the 'ethnographic genre' in terms of its use of observation and participation (Atkinson, 2014: 8). However, as I illustrate, this

has not been occasional and ad hoc, but sustained and prolonged interaction and observation, over a four year period, of one project group, hence its embedded ethnographic nature. That aside, it should be stressed that neither is the role of knowledge integration and reflection facilitator an auto ethnographic[1] account of being part of an interdisciplinary research project. Whilst the 'insider' perspective has been provided by several interdisciplinary projects this is generally conducted by someone who is part of the research team and whose main role is to conduct the research, not reflect on or encourage the process (see Benard and Cock-Buning, 2014; Depres and Lawrence, 2004; Goebel et al., 2010). In only a handful of cases has a researcher been employed in an interdisciplinary project to conduct a specific and ongoing reflexive appraisal of the collaboration (see Donaldson et al., 2010, Mierlo et al., 2010). In some instances this has involved researcher's taking on a dual role of conducting research whilst also appraising inter and transdisciplinary processes, such as Miah et al., (2015) and their role of being 'transdisciplinary champion' whilst researching energy efficiency within a factory , (see also Polk et al., 2015 for a team approach). In contrast, externally-led, retrospective and formal evaluation practices are becoming more commonplace within interdisciplinary projects, particularly in response to the drive for better evaluation of collaboration. PROTEE, for example, is one such method which involves external auditors meeting formally with team members at set stages throughout the course of a project (see Duret et al., 2000; Valve and McNally, 2013). Another approach is to evaluate interdisciplinarity across several projects. For example, Lyall et al., (2013) appraised the role of funding agencies in encouraging and enabling interdisciplinarity across several projects; whilst Boix Mansilla et al., (11: 2015) 'examined the markers and conditions for successful interdisciplinary collaborations' using case studies from nine research networks. These latter two approaches to evaluation are undoubtedly valuable. However, they are marked out by their external and retrospective approaches. The role of knowledge integration and reflection facilitator is very much continual, integrated via its ethnographic position, and responsive.

In SEFS, I, as knowledge integration and reflection facilitator, appraised and analysed the project. I was an ongoing presence in the everyday running of the project – from attending and contributing to meetings, helping at participant workshops (see: *Supplementary Information - Figure 3*), being party to all email and other forms of communications and any of the other mundane, day-to-day elements of being involved in a long-term research project. In doing so, I kept a field diary of all activities, and audio recorded meetings, one-to-one interviews with participants and reflexive team workshops (see below); all of which was transcribed and analysed using thematic etic and emic coding. This 'on-the-ground' and 'of-the-moment' involvement enabled me a full appreciation of the project's trajectory and that of those involved. It could be argued that such intense involvement is actually counterproductive to an appraising and reflexive role, becoming burdened with the 'nitty gritty' of a project, instead of focusing on the bigger picture and the project's key successes and milestones. However, as this article argues, it is the particulars of a project, the everyday encounters and interactions which are crucial to understanding and valuing how interdisciplinarity is shaped within a project; and this is a key focus of the knowledge integration and reflection facilitator.

4.1 Reflexive Review

Using qualitative methods I constructed a programme of reflexive review to encourage interdisciplinary working and to understand and evaluate the project's journey (see: *Supplementary Information - Figure 4)*. As Fazey et al. (2014: 218) note, qualitative methods have the advantage of 'identifying intangible factors' and are capable of capturing 'culture, behaviour, practice, opinion and experience' of interdisciplinary collaborations. This reflexive programme involved both individual and group activities. Individually, quarterly one-to-one interviews with each member of the core

[1] Auto ethnography refers to an ethnographic practice which focuses on the personal reflections and experiences of the researcher.

team were conducted. Such sessions focused on the individual within the team and their experiences of being involved in the project, enabling them to discuss any issues, areas of conflict, to bring to the fore any specific frustrations or ambitions, and to be open about their feelings towards the project and the rest of the team. This individual approach is something which is often overlooked by those appraising interdisciplinary research, favouring discussions with teams as a whole. However, I found this individual approach invaluable for maintaining and stabilising relationships within the project, and thus the success of its collaboration. As much of the interdisciplinary literature discusses, one of the barriers to successful interdisciplinarity is a lack of understanding and appreciation about the values and approaches of other disciplines (Lau and Pasquini, 2008; Lele and Norgaard, 2005; Lyall and Meagher, 2012; Stokols, 2006). Having a space where team members can speak freely about the project without the fear of offending another team member with their ideas or expectations assisted the smooth running of the project.

One such example of this was the creation of a model for our project by a group of architecture students. The students were tutored by the architect from our team and were challenged with producing a model of Stocksbridge which considered renewable energy technologies. The end product was aesthetically inspiring, and included many elements of possible renewable energy sources from wind turbines, solar PV panels and a hydroelectric power scheme. However, for the Physicists it was essentially useless because there were not any calculations to support the use of these technologies in this locale. This created a conflict situation. By acting as an advocate and speaking individually to each party about their issues with the situation, we were able to move through this period. It became clear that the expectations and values of the different disciplines were at odds. This was overcome by the one-to-one sessions, but also further team activities, as discussed next. Thus, my role as knowledge integration and reflection facilitator was not just about encouraging individual critical reflection, but I also acted as a 'sounding board' for any issues and potential problems. This meant conducting regular one-to-one sessions but also operating an 'open door policy' to team members, whereby they can call or arrange a meeting to discuss any issues whenever they felt they needed to. As Lyall et al., (2013: 66), conclude 'successful programmes' take 'deliberate steps throughout to achieve integration and coherence'. I was essentially 'on hand' to deal with any matters which may have affected the collaborative process.

4.2 Team Integration

Complementing the focus on the individual was a sustained attention to the integration of the team (Lyall et al., 2013). As knowledge integration and reflection facilitator I organised bi-annual team workshops aimed at addressing specific interdisciplinary issues. For example, following the conflict situation discussed above I organised a workshop focused on learning about other members of the team and their backgrounds. Exercises regarding disciplinary conventions and values were undertaken to highlight the significant differences between disciplines and the values and approaches they use. This session also focused not just on academic but on other personal experience and background, for instance non-academic career paths, or networks external to academia. This personal focus was instrumental for appreciating not just the values of different disciplines, but also giving credit to the different personalities and experiences at work. As some of the interdisciplinary literature considers, 'personality may be more significant than discipline base' (Lyall and Meagher, 2012: 614), yet the extent of its influence is often 'neither noticed nor acknowledged' (p.613) (see also: Bruce et al., 2004; Jeffrey, 2003; Wainwright et al., 2014). For us remaining person rather than discipline focused throughout the research was invaluable to understanding the collaborative approach. Such an approach did not need to define team members and levels of interdisciplinary cohesion by social constructs such as age or gender but rather focused on individual trajectories and personalities.

When we were immersed in the fieldwork of the project, and finding that we were struggling to define what we were doing, I organised a workshop which included exercises aimed at defining the language of the project. As discussed in Section 2, creating a common language is regularly referenced within interdisciplinary literature as a marker of success, and the 'creole' a key finding of Galison's (1997) 'Trading Zones'. However, rarely are guidelines offered as to how to do this. In our case, each of us defined several terms which were currently significant to the project, such as 'technology', 'community', and 'tools'. The differences in these definitions were startling, but the exercise enabled us to understand why we held differing expectations of the fieldwork, and paved the way for a common vocabulary pertinent to our work. A further workshop focused on defining our interdisciplinarity. This involved us trying to creatively depict the shape of our interdisciplinarity to encourage discussion about how the project was interdisciplinary and how we might be able to make sense of it and talk about it to others. Another workshop focused on setting both individual and team goals and risks, which were returned to and reflected upon throughout the course of the project. Whilst another attempted to deflect any issues of conflict surrounding authorship by drawing up some terms of agreement. This continually reflexive approach across the whole of the core team encouraged and maintained open communication and dialogue, built trust (Miah et al., 2015), and created a community of practice (Wenger, 1998). Most importantly, this continuously drove the team to question and think about the project's interdisciplinarity and its effects, both collectively and individually. As a consequence an interdisciplinary toolkit was produced which uses some of the exercises detailed above, to provide a set of guidelines for interdisciplinary research as process (see Author, 2015). Hence, the project became a project within a project with the role of the knowledge integration and reflection facilitator, and its own methods, approaches and effects. It is the significance of these effects which I now turn to.

5. Experiential 'spillover' effects: circulating practices and knowledges

The perceived significant benefit of interdisciplinary and transdisciplinary working is its ability to provide socially robust orientations to 'real world' problems; problems which cannot be solved by any one discipline alone. However, for us, whilst helping towards solving the grand challenge of future energy sustainability was always a priority of our research, it was the smaller experiential effects on each of us which were more readily identifiable and impactful on the way we work. The embedded ethnographic method, applied by the knowledge integration and reflection facilitator, enabled us to appraise the project through an alternative lens, unearthing a specific set of effects which are normally hidden when using more typical evaluative approaches, such as external or retrospective evaluation as discussed above. Being continually reflexive about the practice of our research, not only enabled us to identify ways in which we have all been changed by it, but also encouraged each of us to learn from the experiences and methods of others. Thus we traded knowledge as per Gallison's (1997) Trading Zones, but as we illustrate this was not so much a trade or formal exchange, but through a slow, diffusive process, whereby knowledge spread amongst us becoming synthesized with existing knowledges. Our interdisciplinarity and our methods for encouraging and reflecting upon it had performative effects. Crucially, these effects were interdisciplinary, not least because they involve the diffusion of experiential value from one discipline to another; in other words, we learnt from each other throughout the process of research, but we were also learning from being involved in this project. We were a community of practice, but also, as Polk et al., note (2015: 112), we were a 'community of co-production'; a hybridised community of practice focused on 'mutual responsibility, joint inquiry, and shared purpose'. Furthermore, as the following illuminates, there was multiplicity to this process. In line with Mode 2 approaches, shared practices were articulated differently by different disciplines. Thus, these learnings, and the practices and competencies they travel in, evolved organically.

These spillover effects can be grouped into two primary classifications: firstly those which were a direct result of being involved in the project and which are practical and administrative, and

secondly, and more importantly, those which resulted from exposure to different disciplinary research and teaching practices and research methods. Of course, there was overlap between these two and none of the spillover effects can be taken out of the context of the project scenario they emerged from. It must also be noted that there are a variety of ways of classifying learning in transdisciplinary and interdisciplinary literature already available (see: Thompson Klein, 2013; Mitchell et al., 2015; Scholz and Marks, 2001). However, the important thing I wish to stress is that the value of our learning is very much wrapped up in its mundane, and blindingly obvious nature; and this is an aspect which is somewhat currently overlooked by transdisciplinary and interdisciplinary scholars. The following table provides a brief summary of the spillovers, with further detail and examples given below:

Table 1: ***Spillover effects identified in SEFS***

Type of 'spillover'	**'Spillover' effect**	**Where travelled**	**How**	**What effects**	**Significance for interdisciplinary research**
Practical Administrative	Recognition of the value of a specific project meeting style.	Across the team	Evolved over time. Began with science led presentation format, evolved into longer meetings with thematic discursive focus	Appreciate value in such meetings and will look to use approach in other projects	*Valuing the importance of administrative matters in producing interdisciplinarity. *How simple things like meeting styles need to be agreed on and teams feel they have an appropriate 'space' to offer their views.
Practical Administrative	Email as main communication tool. Used for thinking through and debating key issues	Across the team	Evolved over time. No other option - given lack of physical proximity of team members. Could argue evolved with trust.	Willingness to use email communication in this way in other projects	*Email can be a useful tool in fostering debate in interdisciplinary projects, particularly when physical proximity is an issue. *Is a matter of ensuring agreement from all about how communications are used within interdisciplinary projects.
Exposure to other discipline's pedagogic practices	Diffusion of teaching practices	Across the whole team. Not simply from one discipline to another or from soft to hard science or vice versa.	Occurred through discussions about practices, but also exposure to other disciplines teaching practices through the use of student researchers employed within the project	Teaching approaches of other disciplines employed and valued moving forward.	*Enables evaluation, appreciation and incorporation of other disciplinary teaching methods. *Challenges own disciplinary teaching practices and encourages synthesis between different disciplinary practices *Fosters an interdisciplinary pedagogic culture of valuing, utilising and enquiring about the teaching practices of other disciplines
Exposure to other	Travelling research	Across the whole team	Occurred through exposure to different	Research methods of disciplines	*Enables evaluation, appreciation and

discipline's research methods and practices of research	methods	but main examples where social science methods being employed by Physics (hard sciences)	methods during fieldwork, where the methods of different disciplines within the project were deployed for differing purposes.	within the project used, valued and integrated by other disciplines, with a view to using them in the future.	incorporation of other disciplinary research methods. *Overcomes fears/undervaluing of the methods of other disciplines. *Enables synthesis of differing disciplinary methods- potentially creating new and innovative approaches to research.

As Table 2 illustrates, the project had practical effects. These were project specific, often on the more tedious and administrative margins, but nonetheless were deemed valuable by the team as things they would take forward in other projects, as well as elements they believe had helped to foster successful interdisciplinary collaboration. One such example was meeting style:

> *I really like the long meetings. I can see that they are immensely productive. I think we put people on the same page, not just in terms of area that you are looking at or data that you are considering but the approach and I think they are very valuable. So this is definitely something that I'd like to reproduce in the future. (Geography member B)*

Meetings and other more administrative aspects of research projects are often overlooked in terms of appraising interdisciplinary projects. Throughout the life course of our project we developed a particular meeting style. Long meetings, over three hours, often offsite, and with a thematic, discursive focus became a feature of our research process. Such meetings would not be formally chaired, but instead would involve talking at length and informally about the current issues of the project. This style of meeting was often discussed in contrast to other styles team members had experienced. For instance, more formal 'presentation-question' formats often used in Physics meetings with large numbers of attendees, or seminar style meetings often held in social sciences. Many of our team members planned to use our particular meeting style moving forward, as a means to bring research teams together and to facilitate collaboration. Another more practical spillover effect was the use of email communication to debate key matters amongst the team. Whilst the majority of the interdisciplinary literature favours face-to-face encounters over email communication (Carew and Wickson, 2010; Stokols, 2006), we found email a useful tool for reflection and debate, enabling team members' time to think about the points of view of others before responding. The capacity to use email in this way emerged over time, but was potentially enabled by the trust which was fostered amongst the team. This was generated by the continual reflexive approach to the project, but can also, in part, be explained by the previous connections within the team. We were not all 'strangers' and our previous connections encouraged a degree of commitment and loyalty to the project right from the outset. As several transdisciplinary scholars have argued, gaining trust and loyalty amongst colleagues is vital in transdisciplinary research (Scholz, 2011; Miah et al., 2015).

Secondly, and, most significantly, were the spillover effects experienced as a result of exposure to other discipline's ways of working. Unlike the more mundane forms of learning discussed above, this form of transformative knowledge (Scholz and Marks, 2001) is given prominence and value within contemporary accounts of interdisciplinary and transdisciplinary collaboration. One such example involved teaching practices:

> *The thing I have really enjoyed with it has been working with architecture. I have really loved working with architects. And that has had huge implications for education and*

> *teaching rather than research….those architecture students basically get on and do everything that is necessary to deliver that project in a true professional way. And I think that that is just amazing. I'm trying to work with some of the same practices with my third year students. They are going to work collaboratively.*
> *(Geography team member A)*

Teaching was never defined as part of the project, but at various stages students were involved as research assistants, such as the above example, in which architectural students were conducting their 'live project[2]' with the Stocksbridge group. As the above quote illustrates, having access to the teaching practices of other disciplines was revelatory for several team members, offering them new tools and practices to apply and synthesize with their own teaching styles. This exposure not only offered new teaching tools, but in terms of interdisciplinary significance, it challenged a discipline's own teaching practices, provoking an evaluation of existing methods and an appreciation of those of other disciplines. Thus, this spillover could help to foster an interdisciplinary pedagogic culture of enquiring about, valuing and utilising the teaching practices of other disciplines, which can only be of benefit to students and to interdisciplinarity per se.

Other 'spillover' effects linked to learning and teaching concern entrepreneurial education practices, such as the physicists' practice of employing students to help out on research project, thus fulfilling a much needed role in the project, but also benefitting the students academically from being involved in high profile research. For instance, both physics and human geography students helped to facilitate a project event – talking to participants, answering queries about the project, and then feeding back their findings following the event. Thus, human geography students were encouraged to talk about energy and sustainability, whilst physics students engaged in some qualitative methods. Such entrepreneurial education practices can obviously be constrained by the flexibility of funding, but they were highlighted by team members from both human geography and architecture as something they would try to employ moving forward. Similarly, a human geography colleague was impressed with the peer support and peer-led supervision sessions used by the physicists. Again this was classed as something useful that they would utilise into their own practices.

A further key 'spillover' effect resulted from exposure to other discipline's research methods and practices; referred to by Huutoniemi et al. (2010: 84) as a form of 'methodological interdisciplinarity'. Traffic between physics, architecture and geography was multi-directional (see: *Supplementary Information - Figure 1* for details about disciplines which are classified as 'hard' or 'soft' forms of science). Firstly, there was the adoption by one of the physicists of social science qualitative techniques, principally focus groups, to conduct research within their own department:

> *Well I think there is something within the Physics department about the research process which is founded around the laboratory, but you can do a research process about science – outside of the science lab. If you've got a question to ask there are different ways to approach that. One of them is to use the lab….yet the ethnographic process is a valid and genuine research process, which could be applied in other areas and it's actually a really rigorous process… These focus groups I did before Christmas – I'm using that information and disseminating that evidence verbally…you kind of have to go through it and live it to realise how you can use that. (Physics member A)*

After initial scepticism towards some social science methods and their validity, having seen them at work and participated in them, both through the team reflexive sessions and also the Stocksbridge workshops, the physicists were enthused by them. Following some brief training from one of the

[2] 'Live projects' are projects undertaken by architecture students which involve a particular group or community with an architectural objective or need.

human geographers, they used them internally within their own department to discuss current learning and teaching frameworks and plan to use them where possible moving forward. For the human geographers this adoption of social science methodologies by a typically 'hard' form of science was a significant interdisciplinary achievement.

Whilst not as significant, traffic in methods also operated in the opposite direction, from 'hard' to 'soft' science. Often social science disciplines are described in interdisciplinary literature as being subordinate, 'soft' forms of science, providing a service role to 'hard' physical science-led projects (Barry et al., 2008; Barry and Born, 2013; Fortun, 2005; Lyall and Fletcher, 2013). These 'downstream' approaches often involve social scientists being brought into projects to assess the societal factors involved. However, as illustrated above and discussed by Barry et al. (2008) such roles can be inverted. Not only did the Physicists ('hard' science) use qualitative methods to engage with participants during the workshops, but the rest of the team had to become knowledgeable about photovoltaic (PV) and also alternative energy technologies. Throughout the course of the project everyone on the team had to engage with experts in alternative energy technologies, such as industry specialists, and highly knowledgeable domestic users. This was obviously not at the level of the physicists, but knowledge had to be gained and deployed to be able to collaborate fully in the project and with the participants. At one stage one of the social science team members spent three days in a laboratory being taught how to make organic PV cells. Whilst this was not a skill she could take and use elsewhere (particularly given the requirement of specialist equipment), this experience enabled her to appreciate the intricacies of PV technologies and some of the challenges the industry and her academic peers face. It enhanced her knowledge and ability to engage with others about alternative technologies.

Another key example of 'spillover' effects in research methods is that several members of the team (physicists and geographers) found their methodological skillsets inspired and altered by being part of the workshops facilitated by architecture. In particular, architecture's use of visual and creative approaches to depict ideas about how energy in Stocksbridge could be transformed:

> *I think I've learnt a lot from architecture in terms of creative participation – in terms of how you engage people, in terms of how you can do different modes of communicating with people…. I mean the things that really jump out for me is the capacity of the some of the architects we worked with for representing ideas and discussion, in the flow of discussion. (Human Geography member C)*

The above quote echoes those of other members of the team equally impressed and inspired by the architectural methods used. As one colleague said: 'they are great tools for thinking with'. Interestingly, it is how these methods were anticipated as being adopted and synthesized into current disciplinary methodological approaches, rather than being used as standalone methods which is significant. So for instance, one human geographer discussed how they would incorporate these creative techniques into more traditional social science qualitative methods, such as interviews and focus groups. Similarly, the physicist who used focus groups did so in part to discuss how student lab sessions could be improved. Thus, a fusion of methodologies and practices occurred as a result of the interdisciplinary collaboration.

These two examples are particularly important to a crucial argument I wish to make: they show how, through their involvement in the project, team members' practical knowledge was re-contextualised and then re-mobilised, in disciplinary contexts. Furthermore, there is a multiplicity to this re-contextualisation. Specific knowledges and competencies have not just been mobilised and re-contextualised by one discipline, but rather by several, and in different and evolving ways. Nor was such re-contextualisation in one direction, from soft to hard science as may be typically thought, but

rather across and then within disciplines. Put crudely, the above examples show knowledge about qualitative methods moving from soft to hard science; and likewise knowledge about PV technologies and the industry moving in the opposite direction. This links to recent work which suggests that disciplinarity, interdisciplinarity and transdisciplinarity complement each other (Scholz, 2011) often occurring side by side rather than as substitutes for one and other. The significance of such experiential learning must be recognised (Benard and Cock-Buning, 2014: 730) as part of the often hidden value of interdisciplinary collaborations. In that regard, it is the breadth of disciplines involved in the SEFS project that is surely significant. This was not an interdisciplinary project forged from within either the physical sciences or social sciences, but rather one that brought together physics, architecture and human geography. The degree of exposure to difference was therefore considerable, requiring those involved to evaluate and appreciate a very broad and differing set of methods to those they typically used. With regards to significance for future interdisciplinary research, such findings suggest that similarly wide ranging collaborations may be significant for future capacity building. As I expand in the final section, such learning is undoubtedly a transdisciplinary endeavour.

6. A transdisciplinary endeavour

The production of transformative knowledge (Scholz and Marks, 2001) requires 'mutual learning', with stakeholders 'experiencing some form of transformation in their knowledge or perspective' (Carew and Wickson, 2010: 1153; see also: Pohl, 2005). As the above examples elucidate, in line with Mode 2 knowledge production and definitions of transdisciplinary processes (Scholz, 2011), our experiential and practical knowledge was transformed through our research; practices were given new perspectives, approaches notably altered, and new objects brought into view (Thompson-Klein 2014: 73). This transdisciplinary endeavour was simultaneously between disciplines, across disciplines and beyond disciplines (Ramadier, 2004). Practical knowledge has been valued as something which is 'continual, iterative and synthetic' (p.217), circulating amongst all collaborators; being re-defined and re-contextualised in multiple, heterogenous and often mundane ways. As Pohl (2011) discusses, progress in transdisciplinary research lies in the lessons learned and experience gained through collaboration. Progress which can be identified by the transfer of knowledge and experience to future practices; be those academic practices such as the examples of changes to research and teaching discussed above, or non-academic through knowledge circulation amongst other key stakeholders. Importantly for us, and where we feel this paper makes a key contribution, is in the recognition of the mundane, everyday effects of such ways of working and how the role of knowledge integration and reflection facilitator can reveal these.

Our project made progress in speaking to debates about energy futures and their transformative effect upon the spatial environment. Nevertheless, its main contribution, and where the residual value of the project is most evident, is in the direct impact upon the practices and competencies of those involved. Competencies only brought to light by the sustained and specific role of the knowledge integration and reflection facilitator. Interdisciplinary projects are seldom valued on these grounds, but I contend that recognition be given to these experiential context specific changes; these slow burning, hard to identify, sometimes banal, 'spillover' effects, which in the long-term will help provide 'orientations' (Gibbons and Nowotny, 2001) to real world problems because of how they alter academic practice and build capacity. As Lyall et al., (2013: 69) concur, 'a five-year interdisciplinary programme alone cannot provide the silver bullet to solving complex issues'. Attention must be paid to how disciplines and academics are hybridised by their involvement in interdisciplinary projects, producing broader skillsets, networks (Jacobsson et al., 2014) and knowledge bases which will all aid co-productive working becoming the norm not the exception. This diffusive, trickle-down legacy effect will require time, funding, and a significant step change in how interdisciplinarity and transdisciplinarity is perceived and evaluated. As Mitchell et al., (2015: 91) conclude 'small changes, step by step, project by project, eventually lead to revolutionary

changes.' Finally, it must be stressed that our 'spillovers' are particular to the context of our project; and the extent to which they could be identified in other interdisciplinary and transdisciplinary research is unaccounted for. Moreover, it is our approach which is transferable to other projects and the role of knowledge integration and reflection facilitator in aiding and encouraging capacity building and subsequent 'spillover'.

7. Conclusion

This article has drawn attention to the need for a fuller and more holistic appreciation of the value of interdisciplinary working and, in doing so, has advocated the role of knowledge integration and reflection facilitator as a means to achieving this. Beginning with a critique of the existing literature, I have illuminated how the well-trodden approach to evaluating interdisciplinarity misses the intricacy of such collaborative working. Definitions, such as those by Barry et al., (2008), provide an essential vocabulary with which interdisciplinary scholars can begin to discuss their modes of working, however, the complexity of such collaborations remains difficult to appraise. The limited range of methods to recognise and draw out the broader value of interdisciplinary collaboration has prompted scholars to call for a field of research which pays significant attention to the interdisciplinary research process, focusing on practices as well as outcomes. This article has detailed our attempts to do this through the role of knowledge integration and reflection facilitator.

Arguing that there is no 'silver bullet' to creating a successful interdisciplinary project, I have detailed my role as knowledge integration and reflection facilitator and my use of embedded ethnographic techniques as a method for encouraging and appraising the complexity and value of interdisciplinary working. This involved using qualitative techniques, focused both on individuals and the team as a whole, to encourage continual reflexivity of the processes and practices of collaborative research. Furthermore, this role meant being flexible to the needs of the project, thinking creatively how to handle issues and promote co-production and reflexivity. I contend that the role of knowledge integration and reflection facilitator has been vital for encouraging and creating successful interdisciplinary collaboration and for revealing the residual worth of such work.

As articulated, the key value for us has been how we were each changed by the diffusion of knowledges, practices and competencies amongst us. As I have illustrated with examples, these 'spillover' effects were experiential – gained through a fusion of the experience of being involved in a research process exploring the transformative potential of energy futures, combined with the knowledges and practices we gleamed from others and their ways of working. As Mitchell et al. (2015: 90) stress, 'strategic thinking' is required 'about realistic spheres of influence, and how contained research projects can leave a wider positive legacy.' This requires the right structural context - time, funding, flexibility, and, above all else, recognising the need to lay the foundations for interdisciplinary capacity building: capacity building which is encouraged and evaluated by someone in a specific role such as the knowledge integration and reflection facilitator of our project. Some of the most productive routes to achieve this may be through more of the kind of broad spectrum research collaborations detailed by this paper. They provide researchers with prolonged, sustained exposure to different research processes and methods that can then travel back, through day-to-day academic practice, to reshape the skills sets of disciplines.

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Supplementary Information

Figure 1 **- further details of the research team**

Position in team	Academic position/career point	Discipline	Faculty	'Hard' or 'soft' science
Principal Investigator	**Senior Lecturer - mid career**	**Physics**	**Physical Sciences**	**Hard**
Co-investigator	**Professor**	**Human Geography**	**Social Sciences**	**Soft**
Co-investigator	**Senior Lecturer - mid career**	**Architecture**	**Humanities**	**Soft**
Co-investigator	**Senior Lecturer - mid career**	**Human Geography**	**Social Sciences**	**Soft**
Research Associate	**Research Associate - early career**	**Human Geography**	**Social Sciences**	**Soft**
Research Associate	**Research Associate - early career**	**Physics**	**Physical Sciences**	**Hard**
Knowledge integration and reflection facilitator	**Research Associate - early career**	**Human Geography**	**Social Sciences**	**Soft**

Figure 2 **- Goals of the project**

The two main goals of the project were:

- To use participatory approaches to explore questions of energy futures with local communities, bringing together local stakeholders with academic partners.
- To promote and explore interdisciplinary working between a range of academic actors exploring issues of energy futures.

Figure 3 **– Main project events and key meetings July 2012 to Dec 2013**

2012	Event	Aim
July	Full team meeting	Discussing/planning initial exhibition event to engage with interested participants
August	Full team meeting	Further planning for exhibition
September	Exhibition at Stocksbridge	Initial event designed to engage with potential participants on issues of energy
October	Full team meeting	Planning of workshop 1, and planned timetable of events
November	Workshop 1	To engage with participants about energy futures within Stocksbridge
December	Full team meeting	Discussion and planning of next workshop
2013		
January	Full team meeting	Discussion and planning of next workshop, including creation of a workbook
February	Workshop 2	Further energy discussions and subsequent

		creation of 5 sub projects
February	Full team meeting	Discussion and planning of next workshop
March	Workshop 3	Fleshing out of the 5 projects
March	Weekly drop ins at local café begin	Opportunity for participants and other interested local parties to meet with researchers and discuss the project and sub projects.
April	Full team meeting	Discussion of next workshop
May	Workshop 4	Project group present back to main group
June	Workshop 5	Project updates
August	Full team meeting	Planning workshop 6
September	Workshop 6	Project updates
September	Architecture 'Live' project begins	Working with the 'improving local community project group to improve energy efficiency in the Inman Pavilion.
October	Architecture 'Live' project ends	Model of Inman Pavilion and energy saving report produced.
October	2 day away day	Full team away day and updates
November	Workshop 7	Project updates and reflections on recent work
December	Full team meeting	Update and plans for 2014

Figure 4 **– Programme of reflexive review 2012-2013**

2012	**Event**	**Aim**
February	Reflexive 1 to 1 interviews	To discuss with individual team member their current thoughts on the project and any issues they may be having
May	Reflexive 1 to 1 interviews	To discuss with individual team member their current thoughts on the project and any issues they may be having
June	Team reflexive workshop	Focus on understanding different disciplinary conventions and values
October	Reflexive 1 to 1 interviews	To discuss with individual team members their current thoughts on the project and any issues they may be having
November	Team reflexive workshop	Focus on communication: creating a common language
2013		
January	Reflexive 1 to 1 interviews	These interviews focused on each individual team member's history in terms of academic career, outside interests etc
March	Team reflexive workshop	Focus on defining our project interdisciplinarity
May	Reflexive 1 to 1 interviews	To discuss with individual team members their current thoughts on the project and any issues they may be having
August	Reflexive 1 to 1 interviews	To discuss with individual team members their current thoughts on the project and any

		issues they may be having
October	2 day away day including one day team reflexive workshop	Focus on setting goals and thinking about risks (team and individual)
October	Focus Group with Architecture students	Focus group with architecture students to discuss their involvement in the live project, and in the project overall
November	Reflexive 1 to 1 interviews	To discuss with individual team members their current thoughts on the project and any issues they may be having

Figure 5 **– Main project conclusions**

Project component	**Conclusion**	**Evidence**
Energy research	Future cannot replace the present in energy research. Power inequalities both within energy visioning research and also energy systems weakens bottom up approaches to energy future visions.	See Krzywoszynska et al., 2016
Energy research	Alternative policy framings are required linking funding not to specific energy technologies but to more broader issues, such as carbon saving, to enable actors to link technological and social innovations in ways which improve the local urban environment	See Krzywoszynska et al., 2016
Interdisciplinary research	Embedded ethnographic methods as a means of encouraging and appraising the complexity and value of interdisciplinary research	Four year project involving an embedded ethnographic researcher who was tasked with exploring, encouraging and evaluating interdisciplinarity through sustained and in depth participant observation within an interdisciplinary team.
Interdisciplinary research	Interdisciplinary research should be valued for the experiential 'spillover' effects it can create and how in the long term these can build capacity within and between disciplines to tackle global challenges.	Numerous spillover effects determined including: practical and administrative; exposure to other disciplines' pedagogic practices; and exposure to other disciplines' research methods and practices.
Interdisciplinary research	Broad spectrum research collaborations, alongside time, flexibility and funding, are required to create ideal environments for interdisciplinary capacity building.	Breadth of disciplines involved in project enabled success of interdisciplinary working. Alongside, having over 4 years to get to know each other, and the flexibility and funding within the project to experiment.